International Journal of Knowledge Based Computer Systems
10 (1) June 2022, 01-09
http://www.publishingindia.com/ijkbcs/

Simulation and Performance Analysis of OFDM System based on Non-Fading AWGN Channel

Diponkor Bala[1*], Md. Ibrahim Abdullah[2] and Mohammad Alamgir Hossain[3]
[1]Department of Computer Science and Engineering, Islamic University, Kushtia, Bangladesh.
Email: diponkor.b@gmail.com
[2]Department of Computer Science and Engineering, Islamic University, Kushtia, Bangladesh.
Email: ibrahim@cse.iu.ac.bd
[3]Department of Computer Science and Engineering, Islamic University, Kushtia, Bangladesh.
Email: alamgir@cse.iu.ac.bd
*Corresponding Author

Abstract: With the development of 4G network technology, gradually 5G wireless communication technology has also been derived and has been studied in deeply. 5G technology has been developed with based on 4G technology to strengthen its advantages, discard its shortcomings, and obtain further breakthroughs in functions. Due to the development of 4G technology, communication services such as downloading and transmitting large-volume data are being accomplished at an enormous speed. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier data transmission system that converts high-speed data streams into multiple parallel low-speed data streams by serial/parallel conversion, and then distributes them to sub channels on mutually orthogonal subcarriers of different frequencies for transmission. This technology has been recognized by the industry as the core technology of the new generation of wireless mobile communication systems. This paper mainly discusses the principle of OFDM-based LTE communication technology, and multi-channel simulation and analysis the performance of OFDM transmission system based on the MATLAB platform.

Keywords: AWGN, LTE, OFDM, Wireless communication.

I. INTRODUCTION

People have used a variety of communication technologies from ancient times to the present, ranging from the most primitive pigeons and carriages through ships and trains in the steam period, to the most recent derivative 5G technology. These different periods represent different levels of people's technological progress. The most recent decade has been the fastest growing stage in the history of wireless communication technology [1] [2]. With people's increasing demand for multimedia services, wireless communication technology has developed from 3G and 4G to the latest 5G in the direction of larger data volume and faster transmission rate [3]. At present, the communication technology that accounts for the largest share of the global communication market is still 4G, and Orthogonal Frequency Division Multiplexing (OFDM) is the core strategy of the fourth-generation mobile communication [4].

In the traditional multi-carrier frequency division multiplexing system [5], in order to prevent internal interference between sub-carriers, each sub-channel uses different carriers to transmit data in parallel. In this system, the sub-carriers are separated far enough to prevent spectrum overlap. Due to this compromised isolation technology, the spectrum efficiency of traditional information transmission systems is very low. Before the equalizer was adopted, people used this multi-carrier method for high-speed communication in the channel. In order to overcome the shortcomings of low spectrum efficiency of traditional strategies, in 1970, Weinstein and Ebert proposed the first OFDM prototype [6]. However, due to the limitations of the technological level and hardware conditions at that time, this new technology has not been put into widespread use. Until 2010, with the support of mature electronic device manufacturing processes and the development of digital technology, it took more than 30 years for OFDM to regain the attention of scientific researchers.

Basically, Orthogonal Frequency Division Multiplexing (OFDM) is a communication technology where a channel divided into several orthogonal sub-channels, convert high-speed data signals into parallel low-speed sub-data streams, and then modulate them for transmission on each sub-channel. After that, the orthogonal signals can be separated by using related technologies at the receiving end, which can reduce the mutual interference between sub-channels ICI [7]. The frequency distribution of subcarriers in OFDM is shown in Fig. 1.

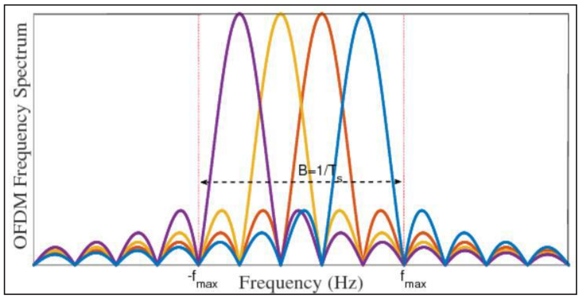


Fig. 1: Frequency Distribution of Subcarriers in OFDM

The signal bandwidth on each sub channel is smaller than the relevant bandwidth of the channel, so the signal on each sub channel can be regarded as flat fading, which can eliminate inter-symbol interference. After separating multiple orthogonal sub-carriers, discrete fourier transform (DFT) and its inverse transform (IDFT) are applied to the parallel transmission system as part of the modulation and demodulation process [8] [9]. This solves the problem of transmission and transmission in a multi-carrier transmission system. The application of fast Fourier transform greatly reduces the complexity of the multi-carrier transmission system. In this way, it is possible to realize FDM without applying a band-pass filter and only through baseband processing.

The OFDM technology is used in various communication systems such as- Wi-Fi 802.11ac, 4G and 5G cellular phone technologies, Wi-MAX, Satellite and so on [10]. OFDM system has been widely used in communication technology in recent years mainly due to its some advantages such as- higher spectrum utilization, excellent anti-multipath interference and anti-fading ability, more sensitive resource allocation, faster asymmetrical transmission rate. Although OFDM has the above excellent technical advantages, some problems have gradually emerged in the actual application process such as- excessive system complexity, more sensitive frequency response, high PAPR (Peak to Average Power Ratio) [11].

All the simulations are implemented on MATLAB 9.6 (2019a) and the system configuration is Core i3-2.40 GHz processor with windows 10 based 64 bit operating system.

The entire paper is organized as follows, Section I contains the introduction of this paper, Section II contain the description of the required fundamental components of the system, Section III contain the working principle of OFDM system, Section IV contain the OFDM system simulation in step by step, Section V describes results and discussion and finally the conclusion of this research work has been drawn in last section.

II. FUNDAMENTAL COMPONENTS

A. Channel Model

The AWGN channel is very popular due to its non-fading properties and simplicity. The time of passing signals through the channel the AWGN channel adds White Gaussian noise to the signal [12] [13]. The Probability density function is always following Gaussian distribution and the equation of Gaussian distribution is expressed as-

$$f_g(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \tag{1}$$

Where x = Random variable

μ = Mean value

σ = Standard deviation

Through AWGN channel a received signal is expressed as-

$$r(t) = x(t) + n(t) \tag{2}$$

Where $x(t)$ = Transmitted signal

$n(t)$ = Additive White Gaussian noise

B. Modulation Methods

At present, in order to meet people's demand for more and faster data transmission, multi-system digital modulation has become more and more popular. In this experiment, the two modulation methods M-PSK and M-QAM were tested separately [14]. Two modulation techniques are analyzed when the control output is the same variable. The waveform expression after these two modulations is as follows:

$$S_i(t) = \sqrt{\frac{2E_s}{T_s}}\, cos(2\pi f_c t + \theta_i) \tag{3}$$

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}}\, a_i cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}\, b_i sin(2\pi f_c t) \tag{4}$$

C. Cyclic Prefix

In the traditional protecting plan, there will be no any signal in the protecting interval, which means there will be a free transmitting period. However, in this condition, the multi-path effect will leads to ICI and ISI. In order to maintain the orthogonality of signals and eliminate the interferences, a series of cyclic prefix is needed to be inserted into the protecting interval that is shown in Fig. 2. In this way, the period difference between one subcarrier and another subcarrier must be an integer. After testing, it shows that if the length of cyclic prefix is greater than or equal to the length of channel's impulse response, the ICI and ISI will be complete eliminated [15].

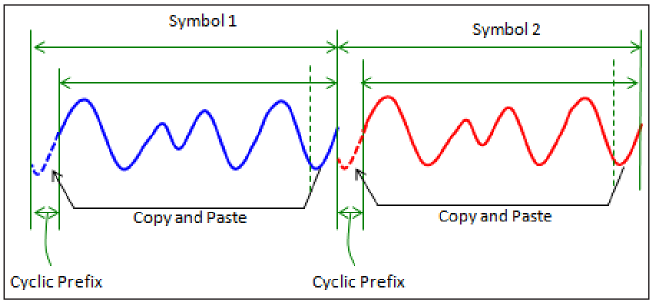


Fig. 2: Subcarrier Frequency after Adding Cyclic Prefix

D. Emitter and Receiver Composition

The following Fig. 3 shows the transmitter block diagram of the OFDM system after the guard interval is added, so that the loss of power and information rate transmission can be calculated.

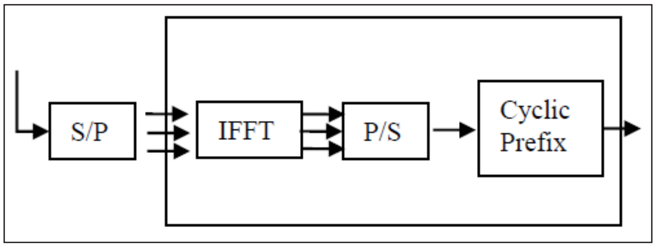


Fig. 3: Emitter of OFDM System

The composition of the receiving electrode is similar to that of the transmitting electrode, but in the opposite direction. The emitter loss function after adding the cyclic prefix can be defined as-

$$Loss = 10 * \log\left(\frac{T_g}{T} + 1\right) \tag{5}$$

III. Working Principle of OFDM System

In this section, the working principle of the OFDM system has been discussed. The block diagram of OFDM system flowchart is shown in Fig. 4. The original source signal is analog and continuous. After baseband modulation (including sampling and filtering), the form of the signal is transformed into a discrete frequency domain signal. Then enter the OFDM module, the discrete signal is decomposed into multiple orthogonal and overlapping parallel sub-carriers, these sub-carriers exist in their respective sub-channels. Next, the motion IDFT or IFFT technology modulates the signal and converts it into an analog signal again [16]. In this experiment, because the number of subcarriers is relatively large, IFFT [17] is used to reduce the algorithm complexity.

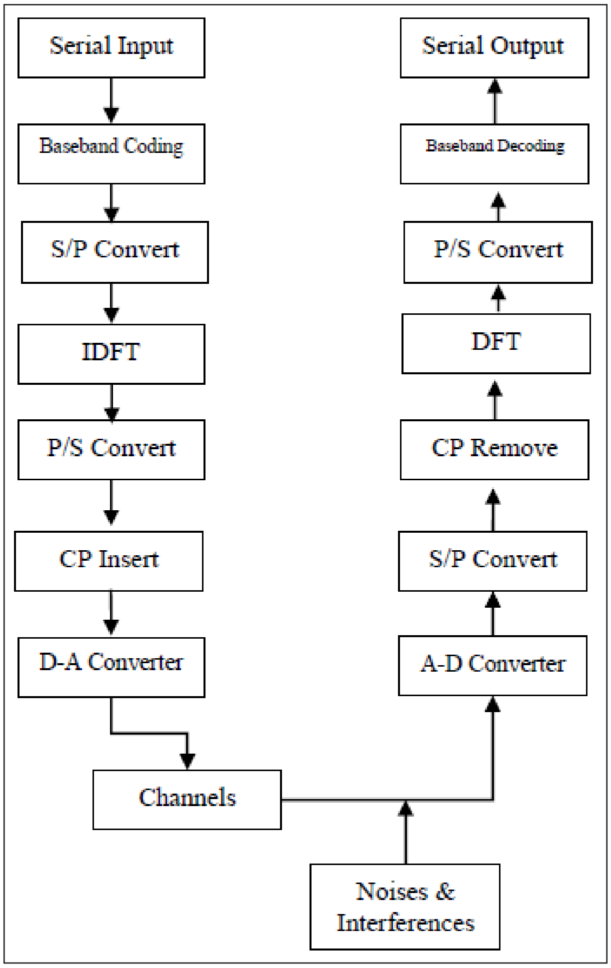


Fig. 4: OFDM System Flowchart

After that, the resulting analog model needs to be added to the cyclic prefix to simply and effectively eliminate inter-channel interference caused by multipath effects. It should be noted that in the process of inserting the cyclic prefix, the duration of the guard interval needs to be determined according to the current wireless channel conditions. According to convention, the length of the guard interval should be 2 to 4 times the square root of the time delay extension. Finally, the parallel signal is converted into a serial signal and input to the transmitting filter for transmission. So far, the transmitting end of the OFDM system has completed its transmission task. The parallel signal sent by the transmitter passes through the physical channel, and is affected by the weakening and noise caused by the channel transmission, and some details will be lost. The specific loss ratio is related to the signal-to-noise ratio (SNR) of the source signal. In order to easily simulate the signal loss caused by the transmission process, this experiment uses a defined signal-to-noise ratio to explore the relationship between it and the signal-to-noise ratio. After receiving the signal, the receiving end will filter it first, and then transmit the obtained signal to the

OFDM receiving end or directly to the information host after demodulation. The specific path selection depends on the result of channel estimation and frame synchronization recovery. After the OFDM receiver receives the continuous serial time domain signal, it first converts it into parallel, and then removes the cyclic prefix of each subcarrier. (Regardless of whether there is a cyclic prefix, only the signal itself is considered when performing FFT or IFFT modulation on the signal, and the cyclic prefix is not considered). Next, use the FFT method to convert the time domain signal into the frequency domain, and input the converted frequency domain response into In the equalizer. In theory, the processed signal does not have any inter-symbol crosstalk. Finally, perform parallel-to-serial conversion and baseband demodulation on the obtained signal. At this point, the work of the OFDM receiver is completely over.

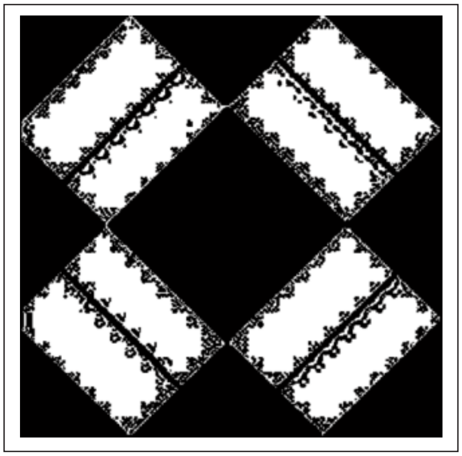
IV. System Simulation

In this section, the simulation of OFDM system has been discussed and analyzed the sequence of the signal changes in the OFDM system.

In order to better control the variables, the experiment did not use randomly generated one-dimensional signals, but used a simple binary image as transmitted data and compare after reception. Other experimental parameters are shown in the Table I.

Table I: Experimental Parameters

Parameters	Value
Data/Noise	-10:5:25
Number of Subcarriers	512
Slot number per frame	20
Sym number per slot	7
Sym number per slot pilot	2
Sym number per slot data	5
Channel	AWGN
Modulator	QAM and MPSK



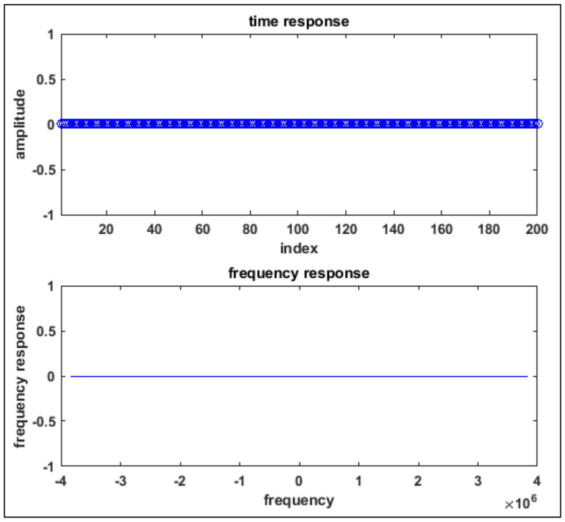


Fig. 5: Data Source and its Time & Frequency Response

Step 1, we choose Additive White Gaussian Noise channel [18] for simulation experiment. The source picture and its time-frequency response [19] are shown in Fig. 5. (In order to save time, from then on, the time frequency analysis is limited to the first 200 sampling points).

Step 2, use 100PSK modulation to output the signal as 100 different phase carriers by phase selecting and the obtained output figures are shown in Fig. 6. Then, use 16QAM modulation to differentiate signal changes in amplitude and the obtained output figures are shown in Fig. 7.

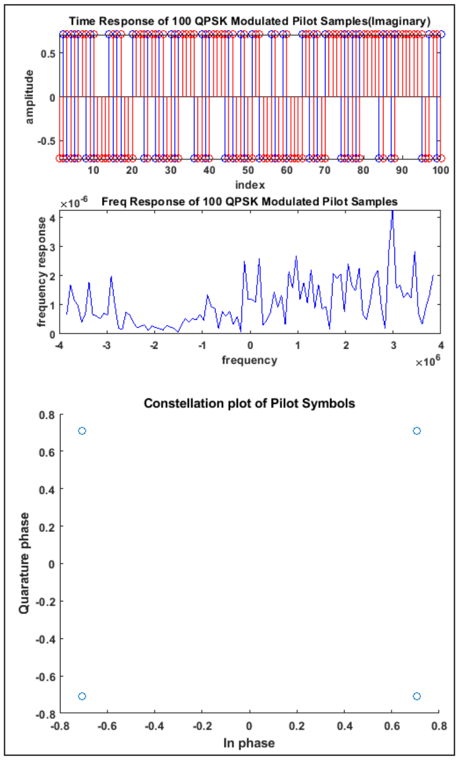


Fig. 6: Time & Frequency Response and Constellation Plot after 100PSK

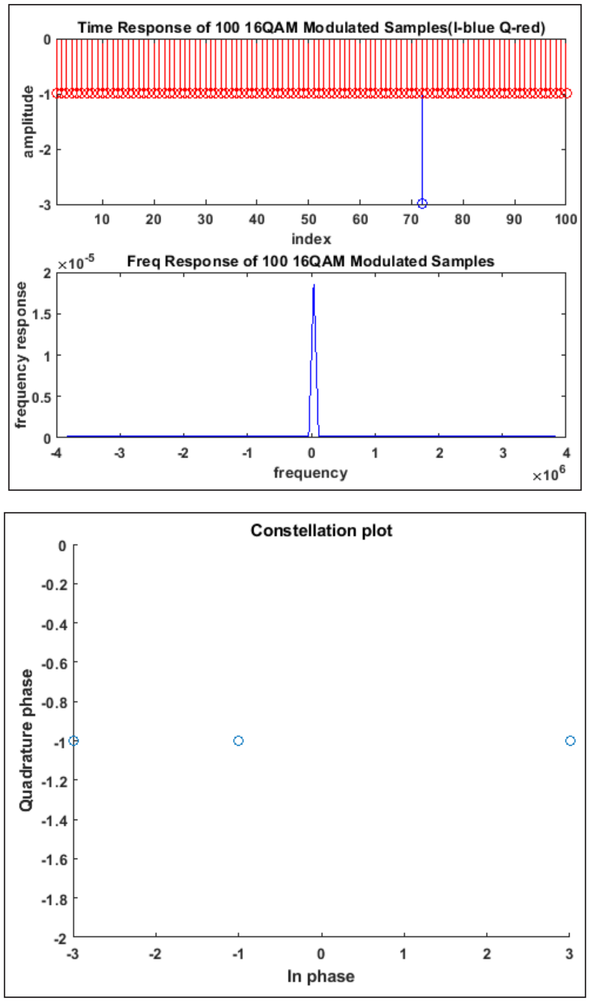


Fig. 7: Time & Frequency Response and Constellation Plot after 16QAM

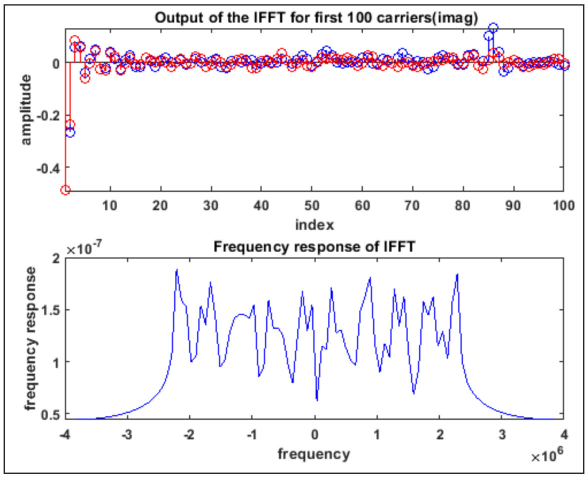


Fig. 8: Output of IFFT

Step 3, in order to add cyclic prefix, apply IFFT to the modulated signal to convert it from frequency domain to time domain and the output of IFFT is shown in Fig. 8.

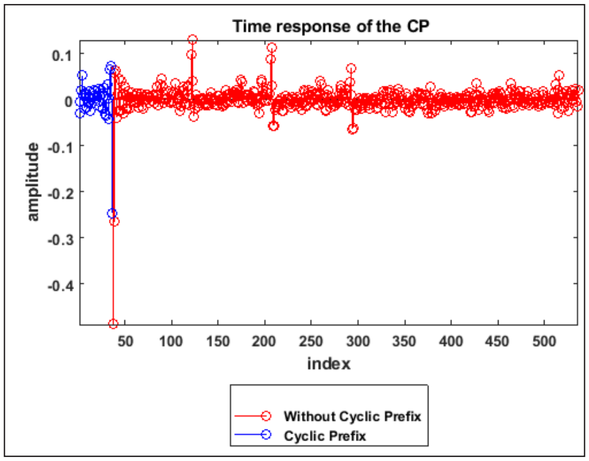


Fig. 9: Time Response with CP

Step 4, add cyclic prefix to the obtained signal. As shown in the Fig. 9, the blue part is the cyclic prefix of the sub-carrier. After the CP is added, the tail of the previous symbol will not fall in the sampling interval of this signal, so that ISI is fully avoided. In addition, due to the cyclic convolution characteristic of the FFT, the signal is regarded as a circle in this step, and a complete signal can be obtained no matter where the FFT window is added. So in this step, CP also eliminates ICI to a certain extent.

Step 5, the signal needs to be upsampled before the data is transmitted from the transmitter to the channel. The obtained figures for time and frequency response of upsampler are shown in Fig. 10. After this, Gaussian noise is added to the signal by the simulated AWGN channel, and the mixed signal is input to the receiving terminal. Then, apply a low-pass filter to the received signal and the obtained figure is shown in Fig. 11. The effect of using a low-pass filter here is mainly to reduce power leakage. Suppress the parts other than the main component of the sub-carrier to reduce the interference between carriers.

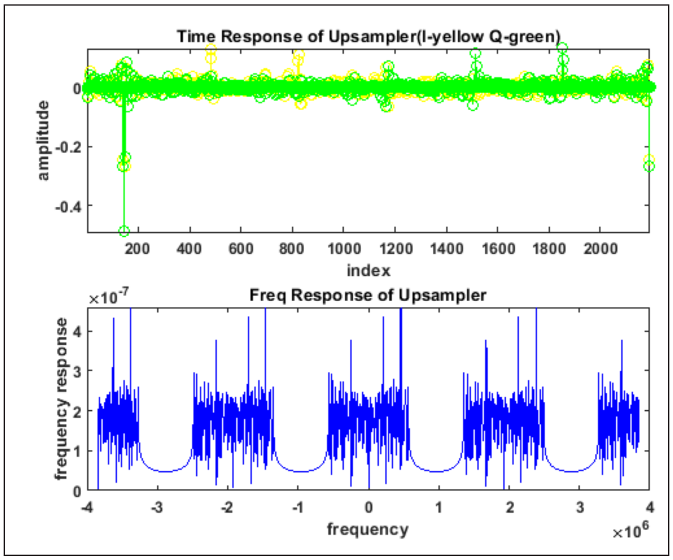


Fig. 10: Time & Frequency Response of Upsampler

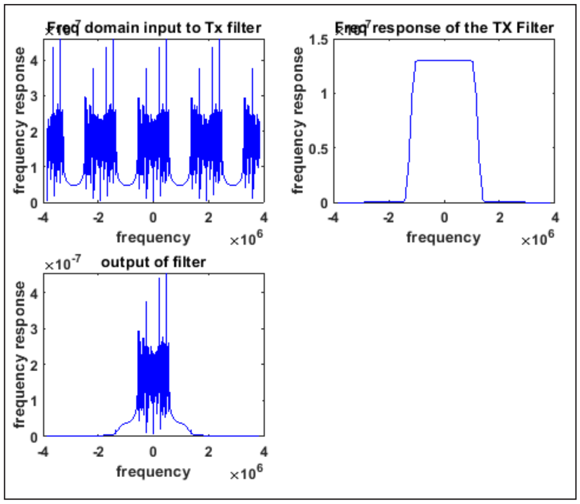


Fig. 11: Output Signal after Tx Filtering

Step 6, apply low-pass filter on receiving terminal to reduce the noise effect, because for image data, the high frequency part is commonly noise that is shown in Fig. 12.

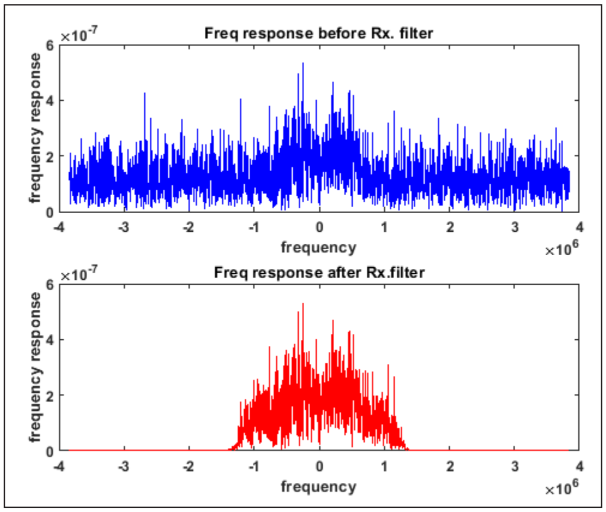


Fig. 12: Rx Filtering

Step 7, after receiving the signal, we do demodulation to the signal we obtained. Note that before the demodulation, the signal must be oversampled, because when these samples without oversampling are sent to the analog-to-digital converter, it may cause false signals to be generated, which is not allowed by the system. The performance of this kind of spurious signal is that when sampling at a frequency lower than twice the highest frequency in the signal, that is, when the sampled value is restored, the signal will no longer contain the high-frequency components of the original signal, showing a false low frequency signal. Therefore, the higher the sampling frequency, the more the signal obtained can represent the details of the symbol.

Step 8, after receiving the signal, we do demodulation to the signal we obtained. Fig. 13 shows the signal response after demodulation when SNR equals 5db.

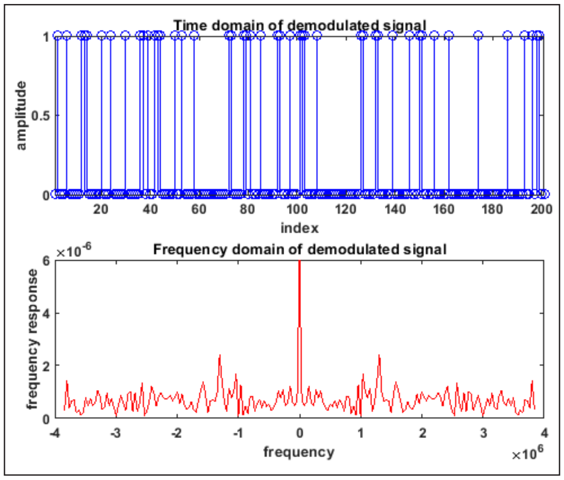


Fig. 13: Time & Frequency Response after Demodulation

Step 9, after demodulation, we get the restored signal. Ideally, the restored signal should be consistent with the signal sent from the output. In order to explore the relationship between SNR and signal transmission loss, here will compare the signal difference between the emitter and the receiver when the SNR is equal to -10db, 0db, and 10db respectively.

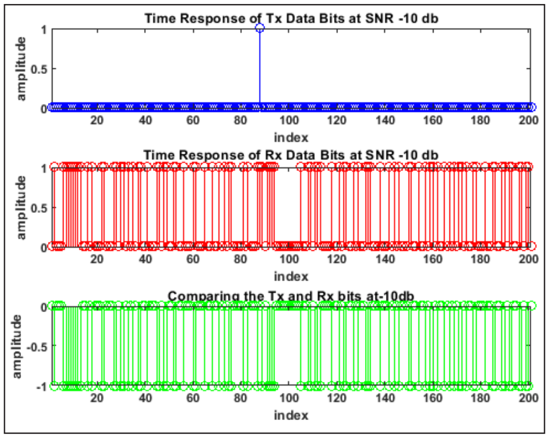


Fig. 14: Comparing when SNR = -10db

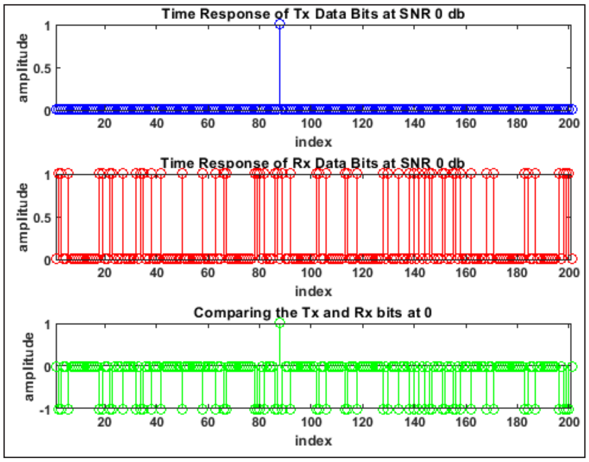


Fig. 15: Comparing when SNR = 0db

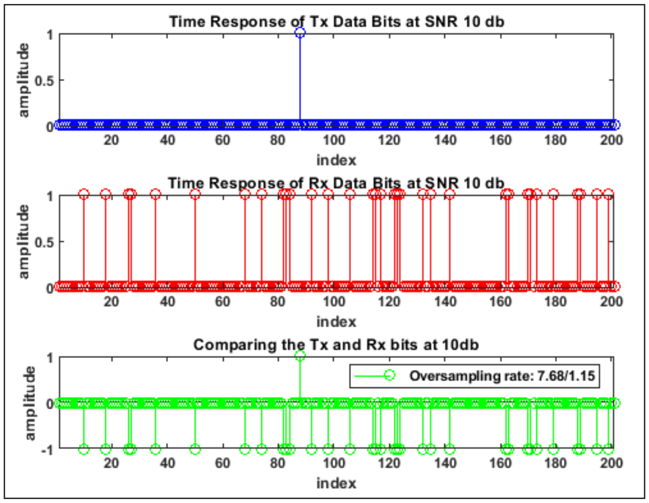


Fig. 16: Comparing when SNR = 10db

V. Results and Discussions

Comparing Fig. 13 and Fig. 5, we can find that after demodulation, the picture at the receiving end has a discernible change from the original picture. By comparing the frequency maps of the two, we can see that in the Gaussian channel, the signal is mixed with uniform and random Gaussian white noise [4]. By observing Fig. 14 to Fig. 16, we can also easily find that as the signal-to-noise ratio gradually increases, the time response of receiving terminal becomes more sparse. Besides, the difference between the output end and the receiving end gradually tends to zero. The mentioned difference above is the Gaussian noise from AWGN channel. From this we can infer that as long as the signal strength is large enough, the OFDM system is fully capable of performing lossless information transmission. We can also conclude that the Gaussian noise obtained from physical channel is uniform and random.

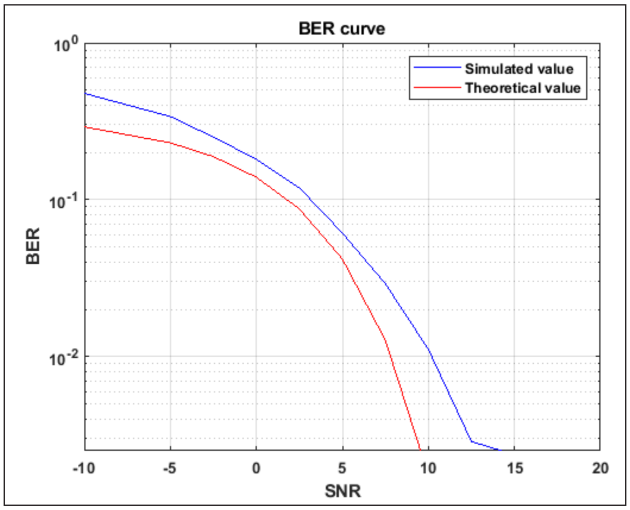


Fig. 17: BER vs. SNR Graph for Image Data

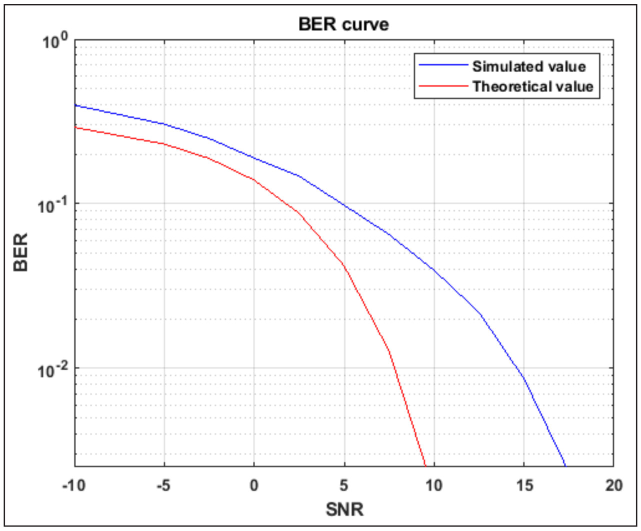
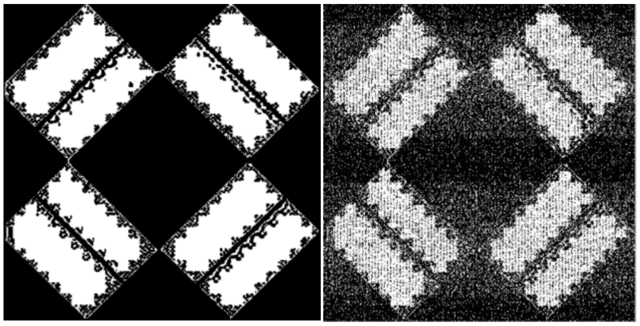
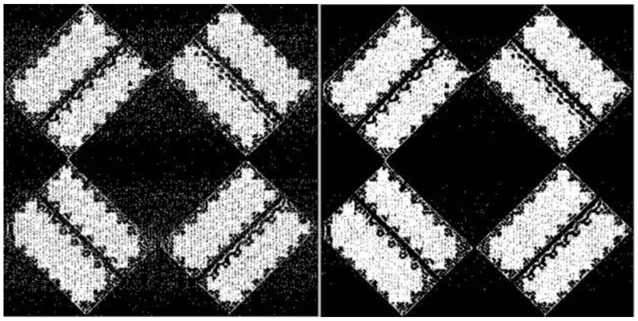


Fig. 18: BER vs. SNR Graph for Random Data

It can be seen from Fig. 17 and Fig. 18 that when the source input frequency is fixed, the BER decreases monotonically with the increase of SNR. In this experiment, in order to simulate the LTE performance, the output image's SNR is limited from 5dB to 25dB.



(a) Original (b) SNR = 5



(c) SNR = 15 (d) SNR = 25

Fig. 19: Comparison at the Receiving Terminal under different SNR

From the above Fig. 19, we can find that as the SNR increases, the Gaussian noise contained in the picture of the receiving terminal decreases. For the test picture used in the current experiment, when the value of SNR is between 0-5, the system simulation has the highest degree of excellence, which is closest to the theoretical curve.

In addition, by comparing the output of Fig. 17 and Fig. 18, we found that when the system input is random multi-frequency noise, the BER result is roughly the same as the test image. However, as the SNR increases, the goodness of fit of the BER of multi-frequency signals is lower than that of a single frequency.

VI. Conclusion

This article first briefly introduced the basic ideas of the OFDM system. Then the working principle of the OFDM system is described in detail according to the module sequence in Fig. 17 and Fig. 18. Then use experiments to analyze the information transmission performance of the OFDM system under the AWGN channel. The results obtained from the experiment also verify the advantages and disadvantages of OFDM mentioned above. In addition, the experiment can further explore the transmission performance of OFDM under different conditions by adding other channel tests.

The most valuable development direction of OFDM in the future is multi-antenna technology. Because multi-antenna technology can ideally increase system capacity and highlight system characteristics, and can significantly improve network stability and reliability, and greatly increase signal coverage, it is especially suitable for use in Internet and multimedia services. The MIMO-OFDM system combines MIMO technology and OFDM technology, which greatly improves the performance of the system. In the future, only if the shortcomings are overcome, OFDM can play a greater role in the post-5G era.

Acknowledgment

The authors would like to cordially thank all the teachers of the Department of Computer Science and Engineering, Islamic University, Bangladesh and most importantly our beloved parents for their continuous support.

References

[1] W. Stallings, *Wireless Communications & Networks,* 2nd ed. USA: Prentice-Hall, Inc., 2004.

[2] H. Viswanathan, and M. Weldon, "The past, present, and future of mobile communications," *Bell Labs Technical Journal*, vol. 19, pp. 8-21, 2014, doi: 10.15325/BLTJ.2014.2335491.

[3] Q. K. Ud Din Arshad, A. U. Kashif, and I. M. Quershi, "A review on the evolution of cellular technologies," *2019 16th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, 2019, pp. 989-993, doi: 10.1109/IBCAST.2019.8667173.

[4] Y. Li, and G. Cheng, "Fourth generation wireless communication network," *2013 3rd International Conference on Consumer Electronics, Communications and Networks*, 2013, pp. 312-315, doi: 10.1109/CECNet.2013.6703334.

[5] R. Prasad, and S. Hara, "An overview of multi-carrier CDMA," *Proceedings of ISSSTA'95 International Symposium on Spread Spectrum Techniques and Applications*, 1996, vol. 1, pp. 107-114, doi: 10.1109/ISSSTA.1996.563752.

[6] S. B. Weinstein, "The history of orthogonal frequency-division multiplexing [History of Communications]," *IEEE Communications Magazine*, vol. 47, no. 11, pp. 26-35, Nov. 2009, doi: 10.1109/MCOM.2009.5307460.

[7] H. Lian, R. Zhao, B. Hu, and H. Pang, "Simulation and analysis of OFDM communication system," *2010 The 2nd International Conference on Industrial Mechatronics and Automation*, 2010, pp. 677-680, doi: 10.1109/ICINDMA.2010.5538218.

[8] S. Coleri, M. Ergen, A. Puri, and A. Bahai, "Channel estimation techniques based on pilot arrangement in OFDM systems," in *IEEE Transactions on Broadcasting*, vol. 48, no. 3, pp. 223-229, Sept. 2002, doi: 10.1109/TBC.2002.804034.

[9] S. Weinstein, and P. Ebert, "Data transmission by frequency-division multiplexing using the discrete fourier transform," *IEEE Transactions on Communication Technology*, vol. 19, no. 5, pp. 628-634, Oct. 1971, doi: 10.1109/TCOM.1971.1090705.

[10] T. Hwang, C. Yang, G. Wu, S. Li, and G. Ye Li, "OFDM and its wireless applications: A survey," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 4, pp. 1673-1694, May 2009, doi: 10.1109/TVT.2008.2004555.

[11] Y. Wu, and W. Y. Zou, "Orthogonal frequency division multiplexing: A multi-carrier modulation scheme," *IEEE Transactions on Consumer Electronics*, vol. 41, no. 3, pp. 392-399, Aug. 1995, doi: 10.1109/30.468055.

[12] A. R. James, R. S. Benjamin, S. John, T. M. Joseph, V. Mathai, and S. S. Pillai, "Channel estimation for OFDM systems," *2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies*, 2011, pp. 587-591, doi: 10.1109/ICSCCN.2011.6024619.

[13] L. Gopal, and M. L. Sim, "Performance analysis of signal-to-noise ratio estimators in AWGN and fading channels," *2008 6th National Conference on Telecommunication Technologies and 2008 2nd*

Malaysia Conference on Photonics, 2008, pp. 300-304, doi: 10.1109/NCTT.2008.4814291.

[14] A. Mráz, and L. Pap, “General performance analysis of M-PSK and M-QAM wireless communications applied to OFDMA interference,” in *2010 Wireless Telecommunications Symposium (WTS)*, 2010, pp. 1-7, doi: 10.1109/WTS.2010.5479673.

[15] M. Batariere, K. Baum, and T. P. Krauss, “Cyclic prefix length analysis for 4G OFDM systems,” *IEEE 60th Vehicular Technology Conference, 2004. VTC2004-Fall. 2004*, 2004, vol. 1, pp. 543-547, doi: 10.1109/VETECF.2004.1400066.

[16] R. Prasad, *OFDM for Wireless Communications Systems*, Artech, 2004.

[17] L. M. Rajeswari, and S. K. Manocha, “Design of data adaptive IFFT/FFT block for OFDM system,” *2011 Annual IEEE India Conference*, 2011, pp. 1-5, doi: 10.1109/INDCON.2011.6139435.

[18] H. Al-Ghaib, and R. Adhami, “On the digital image additive white Gaussian noise estimation,” *2014 International Conference on Industrial Automation, Information and Communications Technology*, 2014, pp. 90-96, doi: 10.1109/IAICT.2014.6922089.

[19] L. Galleani, “Time–frequency analysis of the impulse response,” *IEEE Transactions on Signal Processing*, vol. 67, no. 5, pp. 1280-1295, Mar. 2019, doi: 10.1109/TSP.2018.2890365.